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REPORT OF INVESTIGATIONS—NO. 53

A UNIQUE CLAY FROM THE GOOSE LAKE, ILLINOIS, AREA

BY

R. E. GRIM AND W. F. BRADLEY

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Topographic Mapping in Cooperation with the United States Geological Survey.
This Report is a Contribution of the Section of Geological Resources, Division of Petrography.

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(78242)

May 1, 1939

ILLUSTRATIONS

A UNIQUE CLAY FROM THE GOOSE LAKE, ILLINOIS, AREA[1]

By

R. E. Grim and W. F. Bradley[2]

ABSTRACT

A deposit of nonbentonitic clay has been found in the Goose Lake area of Illinois. The clay has unique properties and composition, and it is marketed under the trade name "Grundite." Its chief constituent was first thought to be beidellite, but further detailed microscopic, X-ray, and chemical studies have shown that it is composed of a distinctive mica-clay mineral of the illite group. The clay possesses properties of plasticity, strength, and gel formation which have caused wide usage in a variety of fields. The occurrence, constitution, and properties are discussed.

INTRODUCTION

Recent petrographic research of the Illinois State Geological Survey has led to the discovery of a new deposit of sedimentary nonbentonitic clay[3] with unique composition and properties. It is lower Pottsville in age and occurs in the pit of the Illinois Clay Products Company, NW. ¼ NW. ¼ sec. 11, T. 33 N., R. 8 E., Grundy County, Ill.

The essential constituent of the clay was first thought to be the clay mineral, beidellite, but detailed microscopic, X-ray, and chemical study have shown it to be composed of a distinctive clay mineral of the illite group. This member of the illite group differs from other illites which have been studied in its properties and in the physical properties it imparts to the clay composed of it. The clay is unique in possessing oil decolorizing ability, high bonding strength, excellent mud-forming properties, and other characteristics not possessed by the argillaceous materials that have been investigated, such as the Pennsylvanian shales of Illinois, which are also composed of illite.

It is the purpose of this paper to describe the occurrence and the composition of this clay, together with the physical properties which have caused its extensive commercial utilization.

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[1] Presented at the Fortieth Annual Meeting, American Ceramic Society, New Orleans, La., March 29, 1938 (General Session on Constitution of Clay). Received April 11, 1938.

[2] Petrographer and Assistant Chemist, respectively, Illinois State Geological Survey, Urbana, Illinois.

[3] The clay will henceforth be marketed under the copyrighted name "Grundite"; it is also marketed to some industries under the name "NaClay."

OCCURRENCE AND CHARACTER

The clay comprises horizon 5 of the section described in table 1. It is green to gray, unlaminated, noncalcerous, nonbedded, nongritty, and possesses the irregular interlocking slickensided-fracture surfaces characteristic of Pennsylvanian underclays in Illinois. Organic material is present in varying amounts, being least abundant in the green clay. Moisture causes the dry, fairly hard clay to become very sticky and plastic.

The other underclays shown in the section (table 1, horizons 3 and 1) are essentially kaolinite[4] clays which also contain some illite. These clays are not considered in this paper.

TABLE 1.—SECTION EXPOSED IN GOOSE LAKE CLAY PIT*

	Material	Thickness
	Pleistocene:	
7.	Peat, loam, marl, or sandy gypsiferous clay.....	0–6 ft.
	Pennsylvanian:	
6.	Limestone: gray, massive, soft, clayey.....	0–6 in.
5.	Underclay: green to gray; frequently lower part green; upper part gray; middle portion mottled gray-green (this relationship not constant)	0–6 ft.
4.	Coal	1–4 in.
3.	Underclay: dark brownish-black; highly fractured; usually contains several thin coal streaks variable distances below top.....	3–5 ft.
2.	Coal	2–6 in.
1.	Underclay, gray-black, slightly gritty, slightly fractured	12 + ft.
	Ordovician (Richmond)	

The Pleistocene materials (horizon 7) are variable in thickness and in distribution. Usually only one of the materials mentioned occurs between the Pennsylvanian sediments and the surface. Where horizon 5 is present, the covering of Pleistocene material is very thin or practically absent.

The Pleistocene-Pennsylvanian contact is irregular. Occasionally horizons 6 and 5 are missing from the section, presumably because of erosion. Experience has shown that where the Pleistocene section contains beds of peat, horizons 6 and 5 of the section are generally absent. In the immediate area in which this section is exposed, the clay under consideration is known to be present over an area of at least several acres in extent.

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[4] Grim, R. E. and Allen, V. T., Pennsylvanian underclays of Illinois: Illinois State Geol. Survey, Rept. Inv. 52, 1938.

* Illinois Clay Products Co., NW. ¼ NW. ¼ sec. 11, T. 33 N., R. 8 E., Grundy County, Ill.

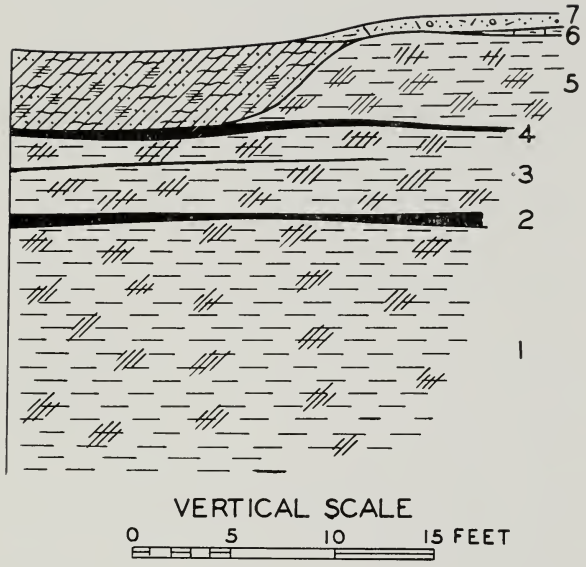

FIGURE 1.—Generalized cross-section of clay deposit in pit of Illinois Clay Products Co., Grundy County, Ill.; horizon 5 contains the clay considered in this paper.

MINERAL COMPOSITION

The green clay is composed almost entirely of a distinctive member of the illite group of clay minerals (see Analytical Data for Illite Constituent). The gray clay also contains kaolinite, varying in amount to as much as 20 per cent of the total material.

The illite occurs in flake-shaped particles of varying size up to 0.015 mm in diameter. Upon working the clay with water, the larger particles are broken down easily to a size of less than 0.0001 mm in diameter. Kaolinite occurs in particles attaining a maximum diameter of 0.02 mm, and they are not easily reduced in size by working the clay with water.

Quartz, in unsorted grains with a maximum diameter of 0.06 mm, is a constituent in varying amounts up to 15 per cent of the total clay. Euhedral grains of pyrite in small amounts are present occasionally. A small amount of organic material, particularly in the gray clay, is present as pigmentary material in the colloid fractions. The exact nature of this organic material is not known. Other rare constituents are grains of zircon, tourmaline, rutile, glauconite, and feldspar. All of the feldspars are of the orthoclase and microcline varieties and are relatively unaltered. These nonclay-mineral constituents are similar to those found in other underclays.

The presence of kaolinite was determined on the basis of optical and X-ray data, and inasmuch as the characteristics[5] of this clay mineral are well established, a presentation of the analytical data is unnecessary. The member of the illite group was identified on the basis of optical, X-ray, and chemical data. This clay mineral was found to be a distinctive member of the illite group in that its characteristics are somewhat different from those of other illites which have been studied. It is necessary, therefore, to discuss the analytical data for this constituent in some detail.

ANALYTICAL DATA FOR ILLITE CONSTITUENT

In order to obtain pure material for optical, X-ray, and chemical studies, a sample of the green clay was subjected to supercentrifuge fractionation.[6] The following fractions were obtained: residue, +0.2 micron; colloid fraction A, 0.2–0.05μ; and colloid fraction B, —0.05μ.

The residue is a mixture of illite and the nonclay minerals noted previously. Optical and X-ray analyses show that the colloid fractions are homogeneous mono-mineral material.

The analytical data (tables 2, 3, and 4) are derived from the colloid fractions. In addition to purification, supercentrifuge fractionation has the further advantage of providing oriented aggregates,[7] which are more satisfactory for optical and X-ray studies.

OPTICAL DATA

The optical data (column 1, table 2) were determined on aggregates composed of individuals in relatively uniform crystallographic orientation. These data are incomplete because the aggregates give scant information on the crystal form and orientation of the mineral. Interference figures were obtainable, indicating that $2V = 8°\pm$, and Bx_a(= X) approximately $\perp$ to the base.

Other illites which have been studied (columns 2 and 3, table 2) have slightly higher indices of refraction. The optical data for the illite in the green clay are so similar to those for the iron-rich beidellites from Spokane,

[5] Ross, C. S. and Kerr, P. F., The kaolin minerals: U. S. Geol. Survey Prof. Paper 165E, pp. 151-180, 1931; also Jour. Am. Ceramic Soc., vol. 13, no. 3, pp. 151-160, 1930.

[6] Bray, R. H., Grim, R. E., and Kerr, P. F., Application of clay mineral technique to Illinois clay and shale: Bull. Geol. Soc. Am., vol. 46, pp. 1909-1926, 1935; Ceramic Abs., vol. 15, p. 163, 1936.

[7] (a) Grim, R. E., Petrographic study of clay minerals, a laboratory note: Jour. Sedimentary Petrol., vol. 4, pp. 45-47, 1934; Ceramic Abs., vol. 13, p. 220, 1934.

(b) Clark, G. L., Grim, R. E., and Bradley, W. F., Identification of minerals in clays by X-ray diffraction: Z. Krist., vol. 96, pp. 322-324, 1937; Ceramic Abs., vol. 17, p. 37, 1938.

Washington (column 5, table 2 and column 6, table 4) that, on the basis of optical data alone, it can not be distinguished from such beidellites. This illite, however, has considerably less Fe_2O_3 than beidellites with similar indices of refraction. The optical data fall intermediate between those of beidellite with a similar iron content and those of other illites which have been studied.

TABLE 2.—OPTICAL DATA

	Illite			Beidellite		Nontronite
	(1)*	(2)	(3)	(4)	(5)	(6)
γ	1.574	1.598	1.588	1.536	1.572	1.615
α	1.544	1.565	1.555	1.494	1.523	1.580
γ—α	0.030	0.033	0.033	0.042	0.049	0.035
2V	8° ±	5° ±	5° ±	9°–16°	Small	....
Optical character	(—)	(—)	(—)	(—)	(—)	(±)

* *Column 1*, clay mineral constituent of green clay, horizon 5, Grundy County, Ill. (see section in table 1); *column 2*, Gilead, Calhoun County, Ill.; *column 3*, Fithian, Vermilion County, Ill. (Grim, R. E., Bray, R. H., and Bradley, W. F., Mica in argillaceous sediments: Am. Mineralogist, vol. 22, pp. 813-829, 1937; Ceramic Abs., vol. 17, p. 157, 1938); *column 4*, Beidell, Colo.; *column 5*, Spokane, Wash. (Ross, C. S., and Shannon, E. V., Chemical composition and optical properties of beidellite: Jour. Washington Acad. Sci., vol. 15, p. 467, 1925; Ceramic Abs., vol. 5, p. 100, 1926); and *column 6*, values given by Ross and Kerr (Ross, C. S. and Kerr, P. F., Clay minerals and their identity, Jour. Sedimentary Petrol., vol. 1, pp. 55-65, 1931).

The indices of refraction in table 2 were made by using liquids,[8] which are mixtures of medium government oil ($C_{10\pm}H_{22\pm}$; $n = 1.466$) and monochlor-naphthalene ($C_{10}H_7Cl$; $n = 1.633$). It has been shown[9] recently that the indices of refraction of some clay minerals vary for different immersion liquids. In a mixture of quinoline and glycerine, the index of refraction (γ) of the illite from the green clay is 1.585. In mixtures of iodobenzine and bromobenzine, no change of indices of refraction was found. These data agree with van Baren's[9(b)] conclusion that liquids with the (NH_2) group exert a strong influence on indices of refraction of certain clay minerals. Recent research[9(a)] has also shown that the indices of refraction of some of these minerals vary when they are heated to relatively low temperatures. The index of refraction (γ) of the illite considered here is about 1.620± when heated to 190°C.

[8] Glass, J. J., Standardization of index liquids: Am. Mineralogist, vol. 19, pp. 459-465, 1934; Ceramic Abs., vol. 15, p. 161, 1936.

[9] (a) Correns, C. W. and Mehmel, M., Optical and X-ray identification of kaolinite, halloysite, and montmorillonite: Z. Krist., vol. 94, pp. 337-348, 1936; Ceramic Abs., vol. 16, p. 38, 1937.

(b) van Baren, F. A., Influence of different liquids on refractive index of clay minerals: Z. Krist., vol. 95, pp. 464-469, 1936; Ceramic Abs., vol., 16, p. 257, 1937.

X-RAY DATA[10]

Diffraction data were obtained for oriented flakes[7(b)] in addition to the conventional powder-diffraction diagrams. Both $CuK\alpha$ and $FeK\alpha$ radiations have been employed. Table 3 presents a comparison of the diffraction data for typical illite (column 2, table 2) and the illite from the Goose Lake clay, together with the corresponding Miller indices and calculated structural factors for muscovite. These data indicate that this illite possesses the general structural features of muscovite mica and that the mineral is closely similar to the illite group of this type of mica. The analogy between the illite group and muscovite is perhaps most readily seen if the formula is written as $(KAl \cdot Si)_4 (Mg_3 \cdot Fe_2 \cdot Al_2)O_{10} (OH)_2$ compared to muscovite, which is $(KAlSi_3)Al_2O_{10}(OH)_2$. It is recognized that the existence of base-exchange capacity by illite might be taken to indicate that a minor portion of the magnesium replaces aluminum atom for atom rather than brucite for hydrargillite, as assumed. In fact, such a replacement is assumed in table 5, p. 13. Analytical data on natural silicates are never precise enough to permit actual proof of such refined inferences from individual specimens.

In addition to the lines discernible on powder-diffraction patterns, fiber diagrams of the illite from the Goose Lake clay show four diffuse areas of scattering on the 02*l* and 11*l* row line corresponding to about 3.9Å and 3.1Å. It is quite possible that these are the resultants of unresolved lines at 4.11 and 3.72Å and at 3.20 and 2.98Å, respectively, which are observed fully resolved for muscovite and for several other illites. The diffuse nature of all reflections where l is large compared with h, and k indicates either that the particles are very thin or that the unit cells are irregular in height. It is likely that both factors are operative. Irradiation of moist and dry oriented flakes indicates that the height of the unit cell does not vary with the water content. The unit-cell height is found to be perceptibly shorter than for muscovite. There is some indication that this shortening is accompanied by increased intensity of the 00.12 reflection. Unfortunately the diffuse nature of this line and of $20\overline{1}0$ does not permit distinction between them even on fiber diagrams.

CHEMICAL DATA

The chemical composition of the illite from the Goose Lake clay (columns 1 and 2, table 4) is sufficiently similar to that of other illites (column 3 and 4) to indicate that chemically it is a member of the illite group. This illite contains more water, which is lost at a low temperature (H_2O—), and slightly less K_2O than the other illites which were studied. It is notably different from montmorillonite and beidellite, particularly in the alkali and alkali-earth contents.

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[10] Diffraction patterns were obtained in the Chemical Laboratory, University of Illinois, through the coöperation of Prof. G. L. Clark.

TABLE 3.—X-RAY DIFFRACTION DATA

Indices for muscovite	F for 1 mol.* calculated for MoKα	Illite (typical) d	Illite (typical) I†	Illite (from Goose Lake clay) −0.2 μ d	Illite (from Goose Lake clay) −0.2 μ I†
002	15	9.98	*s*	9.9	*m*
004	26	4.97	*w*	4.95	*ww*
110, 11$\bar{1}$	40	4.47	*s*	4.47	*s*
022	8	4.11	*ww*		
02$\bar{3}$	21	3.7	*ww*	3.9	Very diffuse
11$\bar{4}$	38	3.4	*ww*	3.4	??
006	40	3.31	*m*	3.29	*w*
114	38	3.2	*ww*	3.1	Very diffuse
025	35	2.98	*w*		
115	29	2.84	*ww*		
131, 20$\bar{2}$	90	2.56	*s*	2.56	*s*
13$\bar{3}$	25	2.44	*w*	2.44	*ww*
20$\bar{4}$, 133	95	2.38	*m*	2.38	*m*
22$\bar{1}$	20	2.24	*m*	2.2	*ww*
22$\bar{3}$	34	2.18	*w*		
135, 13$\bar{6}$	65	2.11	*w*	2.1	*ww*
00.10	57	1.98	*m*	1.98	*m*
20$\bar{1}$0	56	1.65	*w*	1.65	*w*
312, 00.12	27	1.64	*m*	1.64	*w*
060, 33$\bar{1}$	130	1.50	*s*	1.50	*s*
20.12, 13.12		1.34	*ww*	1.34	*ww*
400, 068, 33$\bar{9}$	100	1.29	*m*	1.29	*m*
00.16, 264	60	1.24	*w*	1.24	*ww*

* Jackson, W. W., and West, J., Crystal structure of muscovite, $AAl_2(AlSi_3)O_{10}(OH)_2$): Z. Krist., vol. 76, pp. 211-227, 1930; Ceramic Abs., vol. 10, p. 297, 1931.

† *s* = strong, *m* = medium, *w* = weak, *ww* = very weak.

TABLE 4.—CHEMICAL ANALYSES

	Illite (colloid fraction) (1)A*	(2)B	(3) fine	(4) fine	Beidellite (5)	(6) (iron-rich)	Montmorillonite (7)
SiO_2	52.79	50.77	50.10	51.22	47.56	46.06	48.60
Al_2O_3	24.99	24.42	25.12	25.91	20.57	12.22	20.03
Fe_2O_3	4.68	4.21	5.12	4.59	8.58	18.54	1.25
FeO	1.10	1.69	1.52	1.70		0.28	
MgO	2.70	2.77	3.93	2.84	0.80	1.62	5.24
CaO	0.09	0.47	0.35	0.16	2.52	1.66	1.72
Na_2O	0.20	0.17	0.05	0.17	1.28		
K_2O	5.86	5.65	6.93	6.09	Tr		
TiO_2			0.50	0.53		0.84	
Ignition loss	7.14	10.05	6.82	7.49			
Total	99.55	100.20	100.44	100.70			
H_2O+	6.83	8.32	7.18	7.14	6.65	17.26	21.52
H_2O-	5.56	3.11	1.90	1.45	12.01		
SiO_2/Al_2O_3	3.62	3.54	3.39	3.36	3.43	6.40	4.11
SiO_2/R_2O_3	3.21	3.19	3.00	3.02	3.10	3.25	3.95

* *Columns 1 and 2,* Goose Lake area, Illinois. (analyzed under supervision of O. W. Rees, Illinois State Geol. Survey); *column 3,* Calhoun County, Ill.; *column 4,* Vermilion County, Ill. (Grim, R. E., Bray, R. H., and Bradley, W. F., Mica in argillaceous sediments: Am. Mineralogist, vol. 22, p. 823, 1937; Ceramic Abs., vol. 17, p. 157, 1938); *column 5,* Beidell, Colo. (Larsen, E. S., and Wherry, E. T., Jour. Washington Acad. Sci., vol. 7, p. 212, 1917); *column 6,* Spokane, Wash. (Ross, C. S. and Shannon, E. V., Minerals of bentonite and related clays and their physical properties: Jour. Am. Ceramic Soc., vol. 9, p. 94, 1926); *column 7,* Montmorillon, France, (ibid., p. 90).

RELATION BETWEEN CHEMICAL AND X-RAY DIFFRACTION DATA FOR ILLITE

On the basis of the present limited data, few generalizations on clay mineralogy can be actually substantiated. Some concepts, however, are strongly indicated. Investigators in general agree that there are a large number of natural layer silicates in which the fundamental structural unit is an octahedral layer of 6-coördinated ions bound through oxygen, both above and below, to layers of 4-coördinated ions, each tetrahedrally surrounded by oxygen ions. Among the minerals which appear to be minor variations of this general scheme are the micas, the chlorites, pyrophyllite, talc, and numerous clay minerals, including certainly illite and montmorillonite and probably beidellite and nontronite.

For the macrocrystalline micas, it is demonstrated that the triple layers described are charged due to the substitution of Al^{+++} for Si^{++++} in 4-coördinated positions, and these charged triple layers are held together through K^{+} or other ions. In muscovite, the ratio of Si^{++++} to Al^{+++} in the tetrahedral positions is 3. Such micas have a negative charge of 2 per unit cell (equivalent to $2K^{+}$) per triple layer and build large, rigid crystals. In the illite, this substitution of Al^{+++} for Si^{++++} is less extensive; the resultant charge amounts only to about 1 or 1.5 per cell per layer with commensurate alkali content; the layers are thus less firmly bound, and the illites occur only in microscopic or submicroscopic crystals. In montmorillonite, substitution of Al^{+++} for Si^{++++} is still less important, the ratio spoken of above becoming perhaps as great as 20 or 30. Other charges on the layers, however, arise from the substitution of Mg^{++} for Al^{+++} in octahedral positions, such that again the charge per unit cell per triple layer approaches one. For example, an exchange capacity of 100 me. per 100 grams is equivalent to a charge of 0.8 per unit cell per triple layer. The bulk of these charges, however, arises in the middle of a 9 Å unit of layers of packed oxygen ions and can not be so closely approached by alkalis as in the micas, where the charges arise in the outer layers of the unit. This factor of distance presumably governs the exchangeability of the alkalis concerned. Such a concept is in accord with the occurrence of montmorillonite in extremely fine particles, with its ability to add water between the triple layers, forming hydrates, and with its capacity to exchange bases.

In the case of the illite described here, the ratio of Si^{++++} to tetrahedral Al^{+++} is approximately 7, the charge per unit cell per triple layer is approximately 1, and it occurs in particles remarkably smaller than those of other illites encountered to date.

Table 5 lists the proportions of various metal ions reduced to terms of ions per triple layer per unit cell for several illites which have been described. No attempt has been made to standardize the water content. In table 5, suf-

ficient Mg^{++} positions are assumed to be vacant to give rise to a negative charge on the octahedral layer equivalent to the measured base-exchange capacity. No justification can be made for this assumption other than that it improves the agreement with electrical neutrality.

TABLE 5.—CALCULATED NUMBERS OF VARIOUS IONS PRESENT IN ONE TRIPLE LAYER OF UNIT-CELL CROSS SECTION

		Illite			Mica-clay mineral
		(1)	(2)	(3)	(4)
Non-exchangeable alkalis	K^{+}	0.99	1.21	1.04	1.13
	Na^{+}	0.04	0.01	0.04	0.14
	Ca^{++}	0.07*	0.05	0.02	0.08
		1.17	1.32	1.12	1.43
Tetrahedral layers	Si^{++++}	6.99	6.80	6.86	6.60
	Al^{+++}	1.01	1.20	1.14	1.40
		8.00	8.00	8.00	8.00
Octahedral† layers	Al^{+++}	2.95	2.79	2.94	3.68
	Fe^{+++}	0.44	0.52	0.46	
	$Fe^{++} \times \frac{2}{3}$	0.13	0.11	0.13	
	$Mg^{++} \times \frac{2}{3}$	0.17	0.42	0.19	0.16
	Mg^{++} = exchange capacity	0.31	0.16	0.28	0.16
		4.00	4.00	4.00	4.00
Base-exchange capacity		0.31	0.16	0.28	0.16

Column 1, see table 4, column 2, Goose Lake, Ill.; *column 2*, see table 4, column 3, Calhoun County, Ill.; *column 3*, see table 4, column 4, Vermilion County, Ill.; *column 4*, mica-clay mineral taken from E. Maegdefrau and U. Hofmann and modified to compare with other samples (see Micalike minerals as clay substances: Z. Krist., vol. 98, pp. 31-59, 1937; Ceramic Abs., vol. 17, p. 289, 1938).

* Probably due to incomplete removal of gypsum.

† Values are reduced to the equivalent number of trivalent ions, except that sufficient divalent Mg^{++} ions to balance the exchange capacity are included as such.

DEHYDRATION DATA

The dehydration characteristics of the illite in particles of 0.2μ to 0.05μ are given in figure 2 (curve 1); curve 2 (figure 2) presents similar data for another illite in particles of the same size. This illite differs from other illites which have been studied in that it contains more adsorbed water and loses the water of constitution at lower temperatures. Comparisons with published data for other clay minerals are of little value because the particle size is not known in most cases, and recent research[11] has shown that dehydration characteristics are related to particle size.

[11] Kelley, W. P., Jenny, H., and Brown, S. M., Hydration of minerals and soil colloids in relation to crystal structure: Soil Sci., vol. 41, pp. 259-274, 1936; Ceramic Abs., vol., 15, p. 285, 1936.

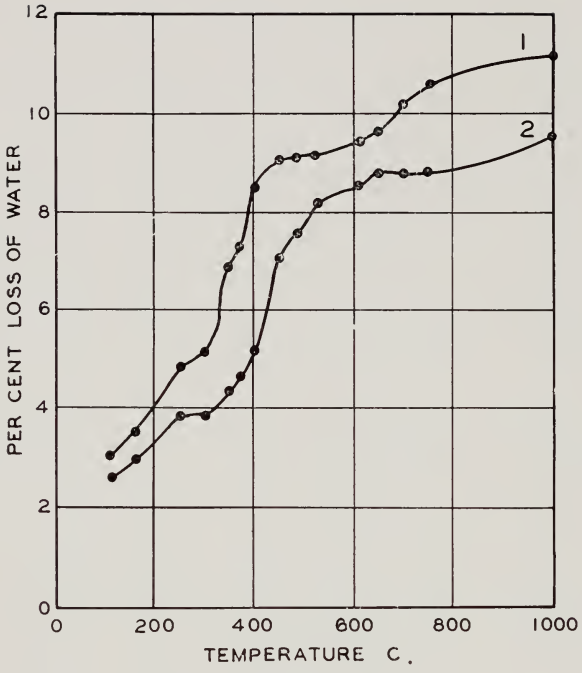

FIGURE 2.—Dehydration curves; curve (1), illite, Goose Lake clay; curve (2), illite, Maquoketa shale, Calhoun County, Ill.

BASE-EXCHANGE PROPERTIES

Base-exchange capacity values for the illite in the Goose Lake clay, determined by the ammonium-acetate method, together with values for other clay minerals are given in table 6. The values for this illite are equal to or slightly higher than the maximum values which have been obtained for other illites.

TABLE 6.—BASE-EXCHANGE CAPACITY

	Illite				
	Colloid fraction A	Colloid fraction B		Montmorillonite	Kaolinite
	(1)	(2)	(3)	(4)	(5)
Inorganic base-exchange capacity (me./100 gr.)	35	38	20–35	60–100	3–15

Columns 1 and 2, Goose Lake area, Ill.; *column 3*, Grim, R. E., Bray, R. H., and Bradley, W. F., Mica in argillaceous sediments: Am. Mineralogist, vol. 22, pp. 813-829, 1937; Ceramic Abs., vol. 17, p. 157, 1938; *columns 4 and 5*, Endell, K., Hofmann, U., and Maegdefrau, E., Nature of clayey raw materials used in German cement industry: Zement, vol. 24, pp. 625-632, 1935; Ceramic Abs., vol., 15, p. 346, 1936.

SUMMARY OF ANALYTICAL DATA

The X-ray and chemical data indicate definitely that the clay mineral of the Goose Lake green clay is a member of the illite group. All of the analytical data show distinctive variations from those obtained previously[12] for other members of this group of clay minerals. These findings support the conclusion reached in the earlier paper that the attributes of the micalike-clay mineral in argillaceous sediments vary considerably in different sediments. Until further examples of the mineral are studied and the limits of variations known, it is not desirable to attempt to limit definite subdivisions of the illite group or to apply specific names to members of the group.

ORIGIN

The clay under consideration is a sedimentary deposit of Pennsylvanian age. The material is clearly an underclay differing from other underclays only because of the presence of a unique member of the illite clay-mineral group. The Pennsylvanian age is indicated as follows: (1) by the character of the clay which is similar to that of other underclays, (2) by the fact that the heavy minerals of the clay are like those of other underclays, and (3) by the relation of the clay to other Pennsylvanian beds exposed (see "Occurrence and Character"). The clay possesses the large number of slickensided-fracture surfaces, characteristic of the underclays in Illinois.

The source of this clay, like that of the other underclays of the Pennsylvanian, is believed to be the somewhat weathered surface material from the area inclosing the region of accumulation. No evidence has been found to indicate that the clay was not deposited as an illite clay, *i.e.*, that the present clay has derived its constitution and properties by weathering or by some other secondary process. Other underclays in Illinois are made up of illite, but the illite in all other underclays which have been studied to date is different from that in the Goose Lake clay, and, as a consequence, the physical properties are different. The explanation of the unique composition and character of this clay is not clear.

NONBENTONITIC CLASSIFICATION OF THE CLAY

Because the green clay in the Goose Lake area has proved to be a satisfactory substitute for bentonite in many industrial uses, the facts should be considered which prove that it is not a bentonite and can not be so classified.

The term "bentonite" was first used by Knight[13] for an unusual clay occurring near Rock Springs, Wyoming. Hewitt[14] showed that the clay desig-

[12] Grim, R. E., Bray, R. H., and Bradley, W. F., Mica in argillaceous sediments. Am. Mineralogist, vol. 22, pp. 813-829, 1937; Ceramic Abs., vol. 17, p. 157, 1938.

[13] Knight, W. C., Bentonite: Eng. Mining Jour., vol. 66, p. 491, 1898.

[14] Hewitt, D. F., Origin of bentonite and geologic range of related materials in the Bighorn basin, Wyoming: Jour. Washington Acad. Sci., vol. 17, pp. 196-198, 1917.

nated as bentonite by Knight had been formed as an alteration product of volcanic ash. In recent years, clays called bentonite have been reported from almost every state. In 1926, following a detailed study of material classed as bentonite prior to this date, Ross and Shannon[15] showed that the following definition was warranted: "Bentonite is a rock composed essentially of a crystalline clay-like mineral formed by devitrification and the accompanying chemical alteration of a glassy igneous material, usually a tuff or volcanic ash. It is advisable to restrict the rock name, bentonite, to a material derived from volcanic ash, since the inherited structure seems to have almost as great an influence on the physical properties as the mineral composition. The characteristic clay-like mineral has a micaceous habit and facile cleavage, high birefringence, and a texture inherited from volcanic tuff or ash, and it is usually the mineral, montmorillonite, but less often, beidellite."

In 1937, after further study, the Committee on Sedimentation of the National Research Council[16] suggested the following definition of bentonite which is essentially the same as that of Ross and Shannon. "Bentonite is a clay formed from the decomposition of volcanic ash and is largely composed of the clay minerals, montmorillonite and beidellite. The rock must be produced by decomposition of volcanic ash and not from the decomposition of other substances. The color range is from white to light green and light blue when fresh. On exposure, the color frequently becomes a light cream and gradually changes to yellow and in some cases to red or brown." This definition of bentonite has been accepted generally.

Clays produced by the alteration of volcanic ash can be detected by their structure and composition. The structure of the clay is inherited from the volcanic tuff or ash. Pirsson[17] has described the structures of tuff and ash, and these structures are preserved in the clay although the material composing the tuff has been altered to clay. Ross[18] has shown that such glass relict structures are characteristic of bentonites and "that these structural forms may be distorted, but they are rarely completely obliterated, and even metamorphosed bentonites have a heterogeneity that can not be ascribed to sedimentary processes but is due to modified glass relict structure."

The accessory nonclay-mineral constituents of bentonites are characteristic. They are partially altered fragments of glass and minerals, originally phenocrysts in the volcanic glass, such as feldspar (commonly orthoclase and oligoclase), biotite, pyroxene, quartz, amphibole, and other minerals typical of volcanic rocks.

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[15] Ross, C. S. and Shannon, E. V., Minerals of bentonite and related clays and their physical properties: Jour. Am. Ceramic Soc., vol. 9, pp. 77-96, 1926.

[16] Twenhofel, W. H., Terminology of fine-grained mechanical sediments: Nat. Res. Council, Rept. Comm. Sedimentation, 1937.

[17] Pirsson, L. V., Microscopical character of volcanic tuffs, a study for students: Am. Jour. Sci., 4 ser., vol. 40, pp. 191-211, 1915.

[18] Ross, C. S., Altered Paleozoic volcanic material and their recognition: Bull. Am. Assoc. Petroleum Geol., vol. 12, pp. 143-164, 1928.

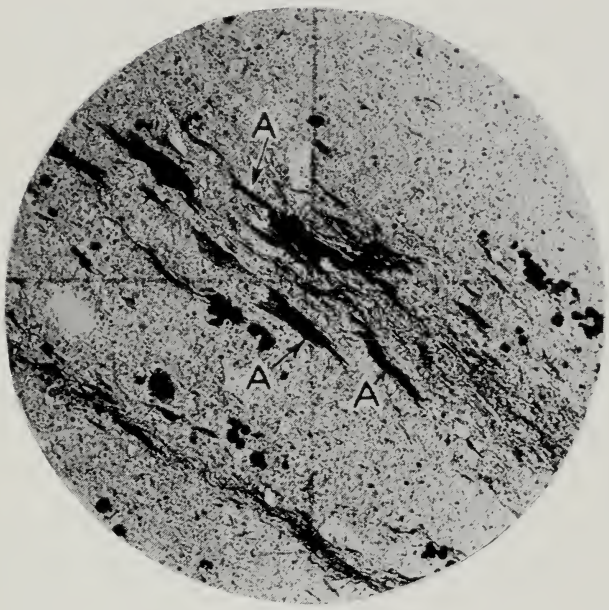

FIGURE 3.—Photomicrograph of thin section of green Goose Lake clay ("Grundite") showing characteristic texture; (*A*) streaks of relatively uniformly oriented particles of illite; the matrix is composed of illite particles in random orientation; 400×.

The clay under consideration does not contain an assemblage of nonclay-minerals like that found in bentonites. Furthermore, as shown in figures 3 and 4, the texture of the green Goose Lake clay is unlike that characteristic of bentonite. The Goose Lake clay contains no structures even remotely resembling the glass relict structures characteristic of bentonites. On the basis of the structure and nonclay-mineral constitution, the material, therefore, is not a bentonite.

All recent work on bentonites has substantiated the work of Ross and Shannon,[15] indicating that the clay-mineral constituent of bentonite is montmorillonite or less often beidellite. The analytical data presented here prove that the green Goose Lake clay is composed of a member of the illite clay-mineral group and not of montmorillonite or beidellite. On the basis of clay-mineral composition, therefore, the clay is not a bentonite. Structure, nonclay-mineral constitution, and clay-mineral constitution all definitely prove that this clay can not be classed as a bentonite.

FIGURE 4.—Photomicrograph of thin section of bentonite showing relict structures; (*A*) fragments of volcanic glass partially altered; 400×.

PHYSICAL PROPERTIES[19]

A distinctive feature of the clay is that it possesses physical properties notably different from those of other clays composed of the same clay mineral, *i.e.*, illite, which have been studied. The clay, as mined, ground and dried, possesses unique properties which cause its extensive use in certain major industries for rebonding foundry molding sand, for oil-well drilling muds, for setting casing in oil wells, for refining mineral and edible oils, and for making special adhesives. Other promising potential uses for the clay are being explored.

REBONDING OF FOUNDRY MOLDING SANDS

"Grundite" is highly plastic; it has a sintering point of 2100°F, a fusion point of 2550°F, and an A.F.A. clay content of 90.5 per cent; it spreads evenly over the sand grains, it has an affinity for water, and it requires a relatively small amount of tempering water (the sand therefore can be worked fairly dry).

[19] The authors wish to acknowledge their indebtedness to J. L. Essex, Chief Engineer, Illinois Clay Products Co., Joliet, Ill., for data concerning the physical properties.

Table 7 shows the bonding effect of "Grundite" with No. 2 Ottawa silica sand (washed and dried). There is little difference in strength when No. 50 sand is used, but the permeability is lower owing to a more compact mold.

TABLE 7.—BONDING PROPERTIES OF "GRUNDITE"

Sand (%)	"Grundite" (%)	Water (%)	Green strength	Dry strength	Permeability	Flowability
94	6	2.0	6.0	15.5	610	88
88	12	2.4	15.0	21.0	480	78

OIL-WELL DRILLING

The Goose Lake clay is sold to the rotary oil-well trade under the trade name of "NaClay." When suspended in water in proper concentration, the mud fluid formed has the characteristics given in table 8.

TABLE 8.—DRILLING MUD CHARACTERISTICS

Mud weight (lb./gal.)	10.0–10.3
Hydrostatic head (lb./sq. in./100-ft. column)	52
Viscosity (sec. Marsh funnel for 1500 cc in and 1000 cc out)	38–45
Gel strength (sec. Marsh funnel) 5-ft. set	2–4
Gel strength (sec. Marsh funnel) 10-ft. set	6–8
Sand content	Nil
Suspendability (% free water operated in 24 hr.)	<2%
p_H value	3.9–5.8
Filter cake (in. thick)	3/16–¼
Filter rate (30 min.)	<1 pint/sq. ft. wall area

With these properties, the mud fluid will properly float out the sand and cuttings, build a good impervious wall, and prevent blowouts and heaving of shale, which are essential functions of a good mud fluid.

OIL DECOLORIZING ABILITY

The data in table 9 show that the clay possesses high bleaching ability and that this property can be augmented by acid activation. The water-white bleach, up to the first appearance of green, is only slightly below that of the well-known Floridin-Attapulgus clay and considerably above some fuller's earths. The color separation of the Goose Lake clay is small, a character that would make it particularly adapted to bleaching animal and vegetable oils.

As a refining clay for vegetable or edible oils, "Grundite" possesses greater efficiency than the American Oil Chemists' Association's Standard Excell clay and substantially equal efficiency to a special grade of Texas earth, used by the major packing companies. The oil retention of "Grundite" is considerably less than either of these clays, and no acidity or rancidity is imparted either to the tested cottonseed or soy-bean oils.

TABLE 9.—BLEACHING DETERMINATIONS*

	Natural clay				Acid-treated			
	Green	Yellow	Red	Blue	Green	Yellow	Red	Blue
"Grundite"	0.9	1.0	1.0	1.0	1.0	1.6	1.9	2.0
Fuller's earth								
Floridin	1.1	1.2	1.4	1.6	0.9	1.1	1.2	1.4
Porter's Creek	0.7	0.9	1.0	1.1	0.9	1.3	1.4	1.5
English XL	1.2	1.3	1.3	1.3	2.0	3.7	3.9	4.1

* Determination on "Grundite" by P. G. Nutting (courtesy of O. L. Jones, president, Illinois Clay Products Co.); determination of remaining samples from Nutting, P. G., Technical basis of bleaching-clay industry: Bull. Am. Assoc. Petroleum Geol., vol. 19, p. 1051, 1935. The "bleach rating" is the ratio of the volume of filtered oil to the clay filtering it; thus 1 unit volume of "Grundite" decolorized 0.9 unit of water-white oil, 1 unit of yellow oil, etc.

SILICATE-CLAY ADHESIVES

Because "Grundite" can be finely ground, has a low moisture content, low lime and iron contents, and an ignition loss of less than 14 per cent, it mixes well with sodium silicates as an adhesive for fiberboard manufacture. In a 30° Bé silicate, only 18 per cent of the clay is required to give a stable adhesive that spreads readily, sets up in a few seconds, and does not stain or strike through the paper. In a 38° Bé silicate, only 21 per cent of clay is required for a similar purpose. The quantity of clay can be reduced and the stability of the adhesive can be enhanced by finer grinding.

MISCELLANEOUS PROPERTIES AND POTENTIAL USES

Additional properties of the green Goose Lake clay are given in table 10.

TABLE 10.

Specific gravity	2.55
Weight/ft.^{3} 200-mesh (lb.)	63
Weight/ft.^{3} 60–100-mesh (lb.)	71

The unique properties of "Grundite" have projected the following potential uses: (1) as a colloidal suspending agent in de-inking newsprint paper, (2) as an emulsifying clay for emulsifying heavy oils and asphalts, (3) as a substitute for dolomite in coating pig-iron molds, and (4) as a binder in insulation mixtures or cements.